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REVIEW

Shared e-scooters, mode substitution and life-cycle greenhouse gas emissions

Patinetes eléctricos compartidos, sustitución modal y emisiones de gases de efecto invernadero en el ciclo de vida

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ABSTRACT

Introduction: Shared e-scooters are promoted as a sustainable alternative to the private car, but the evidence on which modes they replace and on their life-cycle greenhouse gas emissions remains contested. Methods: A systematic review following PRISMA 2020. After deduplication, 433 records were screened and 15 studies were included. Results: Self-reported surveys showed that shared e-scooter trips most often replace walking (37.8 to 46.9 percent) and public transport (25.6 to 32.0 percent), with car replacement of 3 to 12.6 percent; inferred and revealed-preference designs reported car substitution up to 34.4 percent. Life-cycle emission factors ranged from 30 to 320 g CO2e per passenger-kilometre, driven mainly by scooter lifetime, electricity mix and fleet operations. Net benefits appeared only where car trips were replaced. Conclusions: Shared e-scooters reduce greenhouse gas emissions only when they replace motorized trips and when fleets achieve long lifetimes in low-carbon grids; in most observed settings they replace active and public transport trips and can increase emissions.

Keywords: shared micromobility; e-scooters; mode substitution; life cycle assessment; greenhouse gas emissions; travel behaviour.

RESUMEN

Introducción: Los patinetes eléctricos compartidos se promueven como alternativa sostenible al automóvil privado, pero la evidencia sobre qué modos sustituyen y sobre sus emisiones de gases de efecto invernadero en el ciclo de vida sigue siendo controvertida. Métodos: Revisión sistemática según PRISMA 2020. Tras la deduplicación se cribaron 433 registros y se incluyeron 15 estudios. Resultados: Las encuestas autorreportadas mostraron que los viajes en patinete compartido sustituyen con mayor frecuencia la marcha a pie (37,8 a 46,9 %) y el transporte público (25,6 a 32,0 %), con una sustitución del automóvil de 3 a 12,6 %; los diseños inferidos y de preferencia revelada alcanzaron hasta 34,4 % de sustitución del automóvil. Los factores de emisión del ciclo de vida oscilaron entre 30 y 320 g CO2e por pasajero-kilómetro, determinados por la vida útil, la mezcla eléctrica y las operaciones de flota. Los beneficios netos solo aparecieron donde se sustituyeron viajes en automóvil. Conclusiones: Los patinetes compartidos reducen emisiones solo cuando sustituyen viajes motorizados y cuando las flotas logran vidas útiles largas en redes eléctricas descarbonizadas; en la mayoría de los entornos observados sustituyen modos activos y transporte público y pueden aumentar las emisiones.

Palabras clave: micromovilidad compartida; patinetes eléctricos; sustitución modal; análisis de ciclo de vida; gases de efecto invernadero; comportamiento de viaje.

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INTRODUCTION

Shared e-scooters entered cities as a low-emission alternative to the private car, yet the two bodies of evidence that would support that claim point in opposite directions. Hollingsworth, Copeland and Johnson(1)estimated a life-cycle impact of 202 g CO2e per passenger-mile for dockless e-scooters in the United States and concluded that the mode emitted more than the buses and bicycles it displaced.

Gebhardt, Wolf and Seiffert,(2)working from German national travel data, calculated instead that 10 to 15 percent of motorized individual transport trips could be made by e-scooter. Between those two positions sits the question this review addresses: whether shared e-scooters actually replace car trips, and whether, once the full life cycle is counted, that substitution reduces greenhouse gas emissions.

Shared e-scooters spread faster than the evidence about them. Dockless fleets appeared in hundreds of cities after 2017, and operators, investors and city governments promoted them as a solution to short car trips, first-and-last-mile access and urban congestion.(3)

The mode is cheap, app-based and available without ownership, which made it attractive to young, affluent, multimodal riders.(4,5)

At the same time the vehicle is small, light and electric, three properties that invite the inference that it must be clean; whether that inference survives a life-cycle assessment is precisely what the early studies contested.(1,6)

Because the diffusion preceded the research, early regulation and operator claims inherited the assumptions of marketing rather than measurement.

Whether a shared e-scooter reduces emissions is decided almost entirely by substitution, not by the vehicle itself. A trip that replaces walking or a public transport journey adds emissions that would otherwise not have occurred, whereas a trip that replaces a private car or a ride-hailing journey can subtract them.(3,7)

The same vehicle therefore appears green in one city and polluting in another depending on which trips it absorbs, which is why substitution and emissions cannot be assessed separately, because neither a substitution share nor an emission factor is informative about the climate on its own. Substitution is itself measured in two incompatible ways: surveys ask riders which mode they would have used had the scooter been unavailable, a counterfactual that is cheap to collect but prone to recall and social desirability effects, whereas trip-data and revealed-preference studies infer substitution from observed behaviour at the cost of stronger assumptions about the alternative.

A synthesis that keeps these designs apart can explain disagreements that a pooled estimate would conceal, and the present review adopted that separation as an organizing principle throughout the results and discussion.

Recent syntheses have examined fragments of this question without closing it. Wang et al.(7) reviewed what modes shared e-scooters displace but treated emissions as a secondary concern, and Badia and Jenelius(3)reviewed use patterns, perceptions and environmental impacts while reporting substitution estimates that differed widely across cities and survey designs.

Arbeláez Vélez(8)and Calan, Sobrino and Vassallo(9)reviewed life-cycle assessments of shared mobility and shared micro-mobility respectively, but did not connect emission factors to the substitution distributions on which net impacts depend. A meta-analysis by Fearnley and Veisten(10)pooled substitution proportions while leaving life-cycle emission factors outside its scope, and Şengül and Mostofi(11)reviewed sustainability impacts without resolving the direction of the modal shift.

The scope is limited by design to the climate question. It excludes the safety, injury and pavement-conflict literature, which is extensive but does not bear on substitution or emissions, and it excludes operator economics except where operational choices change the emission factor. The scope follows the two-outcome structure of the question and deliberately leaves the adjacent debates to the dedicated reviews that already cover them.(3,11)

The objective of this systematic review was to synthesize the available evidence on the modes replaced by shared e-scooter trips and on the life-cycle greenhouse gas emissions of those trips relative to the substituted modes. The review followed the PICO structure: population of shared dockless e-scooter users and trips; exposure of shared e-scooter use; comparison against the substituted modes, defined as walking, cycling, public transport, private car and ride-hailing; and outcomes of the share of trips replacing each mode and the life-cycle greenhouse gas emissions per passenger-kilometre.

METHODS

Protocol and eligibility criteria

The review followed the PRISMA 2020 statement.(12)Studies were eligible when they reported empirical data on shared, dockless standing e-scooters and quantified at least one of the two outcomes: the mode that e-scooter trips replaced, or life-cycle greenhouse gas emissions expressed per passenger-kilometre or per trip. Substitution could be measured by self-reported surveys, stated-preference experiments, inference from trip records or revealed behaviour, and life-cycle assessments had to include manufacturing and use stages and report global warming potential.

The bibliographic window was 2013 to 2026, matching the specification of the review. Reviews, editorials and conference abstracts without primary data were excluded, as were studies of privately owned e-scooters only and studies of shared bicycles or mopeds that did not disaggregate e-scooters.

The window was chosen because shared dockless e-scooters did not exist before 2017, so earlier records could only describe conventional scooters or bicycles, and the upper bound reflects the volume year of the target journal rather than a judgment about the maturity of the literature.

The exclusion of multimodal studies was applied narrowly: a study of a hub that combined e-scooters with other shared electric vehicles was retained only if the e-scooter results were reported separately, and otherwise it was excluded at full text, which is the single exclusion recorded at that stage. This choice follows from the review question, which asks about shared e-scooters specifically rather than about shared mobility in general.

Search strategy and study selection

Databases: Scopus, OpenAlex and Crossref.

Search strategy: TITLE-ABS-KEY(“shared e-scooter” AND “mode substitution”) and TITLE-ABS-KEY(“e-scooter” AND (“mode shift” OR “mode replacement” OR “substituted mode”)). Two addressed emissions: TITLE-ABS-KEY(“e-scooter” AND (“life cycle assessment” OR “life-cycle” OR “lifecycle”) AND (emissions OR “greenhouse gas”)) and TITLE-ABS-KEY(“e-scooter” AND (carbon OR “CO2” OR climate) AND “life cycle”). A fifth covered the wider micromobility literature: TITLE-ABS-KEY(“shared micromobility” AND (substitution OR “mode choice”)).

Data extraction, risk of bias and synthesis

From each included study a single extraction recorded design, country, sample or data source, population, exposure, outcome, the main result with its estimate and a quality appraisal, with the location of each datum noted in the source document. Substitution shares were extracted as reported for walking, cycling, public transport, private car or taxi and other modes, and life-cycle greenhouse gas emissions were extracted as reported in grams of CO2-equivalent per passenger-kilometre or per passenger-mile.

Where a study reported both a base case and sensitivity scenarios, the base case was extracted together with the range, and where a study reported a net effect against the displaced modes the direction and magnitude of that net effect were preserved.

Because the included designs mixed cross-sectional surveys, trip-data analyses and life-cycle assessments, risk of bias was appraised with an adapted checklist covering four domains: sample representativeness, measurement of the substituted mode, completeness of the life-cycle boundary and transparency of assumptions. A rating of low risk was assigned only when all relevant domains were documented, never as a default; a domain that the authors did not report was recorded as unclear rather than favourable.

Synthesis was narrative and structured by outcome, with substitution and emissions reported separately and then related. A meta-analysis was not performed because the substitution measures were not commensurable across designs and the life-cycle assessments used incompatible system boundaries and electricity mixes; instead, ranges and central tendencies are reported and heterogeneity is described source by source.

The two outcomes were aligned without converting one into the other. Substitution was retained as the reported share of e-scooter trips replacing each mode, and emissions were retained in their published unit of grams of CO2-equivalent per passenger-kilometre or per passenger-mile, so that no conversion factor was imposed on the data. Where a study reported a net effect against the displaced modes, that net effect was reported as the authors computed it, and where a study reported avoided emissions for a specific substituted mode, the direction was preserved.

This conservative approach avoids the double counting that arises when a review recomputes avoided emissions from an assumed substitution share.

RESULTS

Walking and public transport predominated over the car as the modes replaced by shared e-scooter trips in self-reported surveys. In Norway, Fearnley(13)reported that 46.9 percent of riders would have walked and 32.0 percent would have used public transport, whereas 12.6 percent would have used a car or taxi and 6.0 percent a bicycle.

Speak et al.(14)recorded 37.8 percent of trips replacing walking, 25.6 percent replacing a bus and 8.9 percent replacing a car in Bristol, where the university sample had a car mode share of only about 30 percent before the trial.

The share that replaced walking or public transport reached 86.7 percent in Stockholm, 85.6 percent in Gothenburg and 85.3 percent in Malmö in the analysis of Gao et al..(15)(Table 1)

Table 1. Mode substitution shares and life-cycle greenhouse gas emission factors reported by the included studies.

Study	Walking or cycling replaced	PT replaced	Car or taxi replaced	Life-cycle GHG
Fearnley (2022)	52.9 percent active	32.0 percent	12.6 percent	NA
Speak et al. (2021)	37.8 percent walking	25.6 percent bus	8.9 percent	NA
Wan and Bendavid (2023)	27.8 percent active	37.7 percent	34.4 percent	36 to 103 g CO2e/mile avoided
Gao et al. (2024)	85 to 87 percent walk or PT	combined	under 12 percent	modal emission factors
Gebhardt et al. (2021)	NA	NA	10 to 15 percent of car trips	NA
Lee et al. (2021)	13 percent bicycle	NA	32 percent carpool, 7.2 percent taxi	NA
Asensio et al. (2022)	NA	NA	car displacement, revealed	NA
Kazemzadeh and Sprei (2024)	NA	NA	plus 46 percent shift probability	NA
Vinagre Díaz et al. (2023)	NA	50 percent substitute PT	NA	NA
Hollingsworth et al. (2019)	NA	NA	NA	202 g CO2e/mile, 141 to 320
Kazmaier et al. (2020)	NA	NA	NA	165 g CO2e/km, best 46
de Bortoli and Christoforou (2020)	NA	NA	NA	plus 13,000 t CO2eq net
de Bortoli (2021)	NA	NA	NA	60 to 92 g CO2eq/pkt
Judl et al. (2026)	NA	NA	NA	40 to 61 g CO2e/pkm
Jia and Gao (2025)	NA	NA	NA	30 to 124 g CO2eq/km

Note: PT = public transport; GHG = greenhouse gas; pkm = passenger-kilometre; NA = not reported. Percentages refer to the share of e-scooter trips replacing each mode, except Gebhardt et al. (2021), which reports the share of car trips replaceable by e-scooters.

In Norway the substitution profile shifted with trip context. Fearnley(13)reported that on night rides 38.4 percent of riders would have used a car or taxi, 34.3 percent would have walked and 21.8 percent public transport, so that motorized modes were replaced in 60.2 percent of night trips against 44.6 percent of daytime trips.

For trips made to or from another mode, 77.9 percent replaced walking, 14.2 percent public transport and 4.5 percent a car or taxi. Among the fifth of riders who would have changed the entire combined journey, 50.9 percent would have used public transport, 29.5 percent a car or taxi, 13.4 percent walking and 6.3 percent cycling, so that 80.4 percent of those journeys replaced motorized modes. The car replacement share therefore doubled after dark, which locates the motorized substitution in a specific and small segment of trips.

The share attributed to the car rose in inference and revealed-preference designs. Wan and Bendavid(16)inferred an adjusted car substitution of 34.4 percent in London, against 37.7 percent

for public transport and 27.8 percent for active modes, with 36 to 103 g CO2e avoided per mile.

Asensio et al.(17) exploited an evening scooter ban in Atlanta as a natural experiment and measured increases of 9.9 to 10.5 percent in commute travel time and 36.5 percent on event days, which indicates substitution of personal vehicles; the same study contrasted a scooter emission factor of 202 g CO2e per passenger-mile against 414 g for passenger vehicles.

Lee et al.(18)forecast replacement of 32 percent of carpool, 13 percent of bicycle and 7.2 percent of taxi trips in Manhattan.

The London inference was sensitive to demographic adjustment. Wan and Bendavid(16) lowered the car substitution probability from 40.5 to 34.4 percent and raised public transport from 30.9 to 37.7 percent after weighting for the age structure of riders, which suggests that raw inference overestimates car replacement when the sample is younger than the travelling population.

Public transport substitution was heterogeneous across contexts. Vinagre Díaz et al.(19)classified trips in Rome and found that 50 percent of e-scooter trips either substituted public transport or served areas with little transit coverage.

Kazemzadeh and Sprei(20)estimated that e-scooter use raised the probability of shifting a short trip under four kilometres by 46 percent; 49 percent of their sample were frequent e-scooter users, 65 percent cycled several times per week and 79 percent drove several times per week, a profile in which the substituted mode could equally be the car or the transit card.

Gebhardt et al.(2)bounded the German car substitution potential at 10 to 15 percent of motorized individual transport trips.

Life-cycle emission factors spanned an order of magnitude. Hollingsworth, Copeland and Johnson(1)reported 202 g CO2e per passenger-mile in the base case and 141 to 320 g across scenarios. Kazmaier, Taefi and Hettesheimer(21)obtained 165 g CO2e per kilometre in Germany and 46 g in the best case. Judl et al.(22)estimated 40 to 61 g CO2e per person-kilometre in Helsinki, and Jia and Gao(23)reported 30 to 124 g CO2eq per kilometre across 100 European cities.

Manufacturing dominated the life-cycle burden in the assessments that reported stage shares. Judl et al.(22)attributed most of the Helsinki impact to aluminium structures and lithium-ion batteries and found that effective recycling lowered net impacts by 35 to 41 percent, while at fleet level the system contributed only marginally to total urban transport emissions and performed worse than electrified public transport.

Jia and Gao(23)reported a manufacturing burden of 115.6 kg CO2eq per scooter, and Kazmaier, Taefi and Hettesheimer(21)likewise attributed the 165 g CO2e per kilometre mainly to materials and production rather than to the use phase.

The direction of the climate effect depended on the displaced mode. de Bortoli and Christoforou(24)estimated that the Paris free-floating fleet added 13,000 tonnes of CO2eq over one year relative to the modes it displaced, a reversal of the operator claim that the first six million rides had saved 2.3 million kilograms of CO2eq, which the authors attributed to accounting for the full displaced-mode mix and infrastructure. de Bortoli(25)calculated about 60 g CO2eq per passenger-kilometre in low-carbon grids and up to 92 g in China, below the private car but above public transport and walking.

Gao et al.(15)found positive environmental effects in only 19.20 percent of trips in Stockholm, 24.22 percent in Gothenburg and 23.94 percent in Malmö.

Relative to the modes it replaced, the e-scooter sat between the private car and the collective modes. de Bortoli(25)placed shared e-scooters around 60 g CO2eq per passenger-kilometre against about 300 g for taxis and ride-hailing, while public transport and walking remained lower.

The same ranking placed shared e-scooters above shared bicycles, which emitted 33 to 36 g CO2eq per passenger-kilometre, and above shared e-mopeds in low-carbon grids. The comparison inverted the marketing claim: the e-scooter outperformed the car only where the car was actually the displaced mode.

Across studies the car replacement share ranged from 3 to 34.4 percent and the walking share from 24.6 to 46.9 percent, with no single point estimate representative of all cities. The Northern European surveys clustered at the walking-dominated end of that range, whereas the two studies that used trip data or observed behaviour sat at the motorized end.

Scooter lifetime and electricity mix explained most of the spread in emission factors. In the scenarios of Hollingsworth, Copeland and Johnson,(1)the base 202 g CO2e per passenger-mile fell to 177 g with a longer lifetime, 164 g when collection was limited to low-battery scooters, 147 g when collection driving distance was reduced and 141 g under the combined improvements. Battery swapping lowered the estimate of Kazmaier, Taefi and Hettesheimer by 12 percent.

The low values of Judl et al. and Jia and Gao arose from Nordic and low-carbon grids together with higher utilization, whereas the high value of Kazmaier et al. reflected material and production burdens in the German fleet.

Risk of bias was moderate in the self-reported surveys because the substituted mode was hypothetical and the samples came from operator customer lists, and moderate in the model-based forecasts because substitution was simulated rather than observed. Sample representativeness was the most common weakness: the operator customer lists of Fearnley(13)and the university trial sample of Speak et al.(14)were narrower than the travelling public, whereas Kazemzadeh and Sprei(20)recruited non-users and constructed a matched control group.

The life-cycle assessments and the trip-data studies were rated low risk where system boundaries, lifetime assumptions and electricity mixes were reported in full, and no study was rated low solely because information was absent. (Table 2)

Table 2. Characteristics of the 15 included studies.

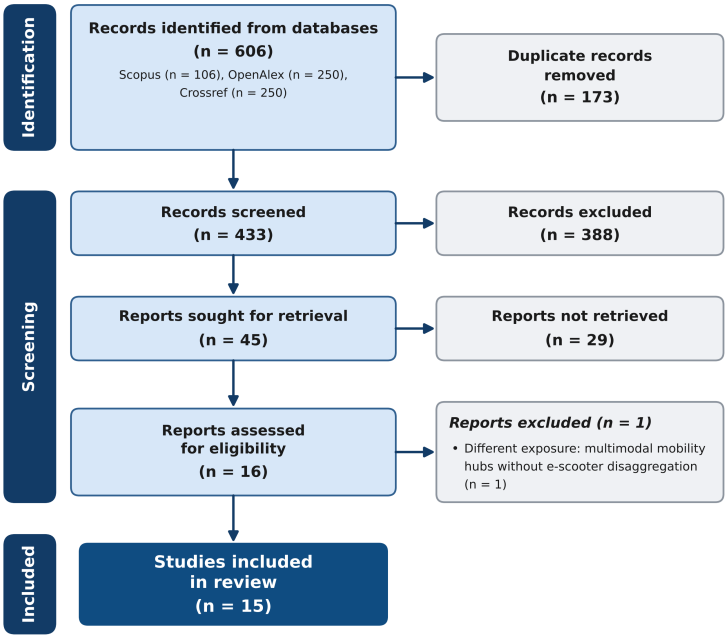
Study (country)	Design	Sample or data	Outcome	Main finding
Hollingsworth et al. (2019), USA	LCA, Monte Carlo	Dockless e-scooter fleet data	GWP per passenger-mile	202 g CO2e/mile base, 141 to 320 across scenarios
Kazmaier et al. (2020), Germany	LCA with user survey	Electric kick scooter fleet	GWP per kilometre	165 g CO2e/km, best case 46
de Bortoli and Christoforou (2020), France	Consequential LCA	Paris free-floating fleet, one year	Net annual CO2eq	Plus 13,000 tonnes CO2eq
de Bortoli (2021), France	Integrated modal LCA	Shared bikes, e-scooters, mopeds	g CO2eq per pkt	About 60, up to 92 in China
Judl et al. (2026), Finland	Cradle-to-cradle LCA	Helsinki dockless system	g CO2e per pkm	40 to 61
Jia and Gao (2025), EU	Data-driven LCA	Operational data, 100 cities	g CO2eq per km	30 to 124
Gao et al. (2024), Sweden	Big-data trip analysis	Trip records, three cities	Replaced mode and CO2eq	85 to 87 percent walk or PT; under 12 percent car
Fearnley (2022), Norway	Web survey	2,585 users	Alternative mode	Walk 46.9, PT 32.0, car/taxi 12.6 percent
Speak et al. (2021), UK	Mixed methods	222 participants	Replaced mode	Walk 37.8, bus 25.6, car 8.9 percent
Wan and Bendavid (2023), UK	Inference vs NTS	Rental e-scooter trips	Substitution and GHG	Car 34.4, PT 37.7 percent; 36 to 103 g CO2e/mile avoided
Vinagre Díaz et al. (2023), Italy	Unsupervised classification	Trip records, Rome	Relation to PT	50 percent substitute PT
Kazemzadeh and Sprei (2024), Sweden	Survey with PSM	805 users and non-users	Modal shift probability	Plus 46 percent
Gebhardt et al. (2021), Germany	Potential analysis	MiD 2017 trips	Car trips replaceable	10 to 15 percent
Asensio et al. (2022), USA	Natural experiment	Travel times, Atlanta	Travel time change	Plus 9.9 to 10.5 percent commute, 36.5 percent events
Lee et al. (2021), USA	Statistical model	Trip and modal data, Manhattan	Substituted share	Carpool 32, bicycle 13, taxi 7.2 percent

Note: GWP = global warming potential; GHG = greenhouse gas; PT = public transport; LCA = life cycle assessment; PSM = propensity score matching; MiD = Mobility in Germany.

The 15 included studies were selected from 606 records identified across the three databases, of which 173 were duplicates and 433 were screened by title and abstract. After 388 records were excluded, 45 reports were sought for retrieval, 29 were not retrieved because no open access copy was accessible, and 16 were assessed in full text.

One report was excluded because it covered multimodal mobility hubs without disaggregating e-scooters, leaving 15 studies. The included set spanned Northern and Western Europe, the United States and Southern Europe, with no study from Asia, Africa or Latin America among those with retrievable full texts (Figure 1).

Figure 1. PRISMA 2020 flow diagram of study selection.



DISCUSSION

The expectation that shared e-scooters would mostly replace car trips did not survive this evidence, and neither did the opposite claim that the mode is uniformly polluting. Hollingsworth, Copeland and Johnson(1)and Moreau et al.,(6)who estimated the Brussels system at 131 g CO2e per passenger-kilometre against 110 g for the displaced modes, concluded that shared e-scooters raise emissions, whereas Gebhardt et al.(2)and Asensio et al.(17)documented genuine car displacement.

The synthesis reconciles the two positions by showing that both are correct within their own measurement frames: the climate outcome is not a property of the vehicle but of the trip it replaces and of the assumptions that govern its life cycle.

The substitution estimates split along method lines, and that split explains much of the apparent contradiction. Self-reported surveys place walking and public transport first and the car last, a pattern found by Fearnley(13)in Norway, by Speak et al.(14)in the United Kingdom and by Gao et al.(15)in Sweden, and it matches the city surveys reviewed by Wang et al.(7)and by Laa and Leth(5)in Vienna.

Revealed and inferred designs produce larger car shares. Asensio et al.(17)showed through a natural experiment that removing scooters pushed travellers into cars, and Wan and Bendavid(16)inferred a 34.4 percent car share in London that exceeded the survey benchmark by a wide margin. Whereas a survey captures the hypothetical alternative a rider recalls, a revealed design captures the mode the rider actually used when the scooter disappeared, and the two quantities need not agree.

The direction of the survey bias is also asymmetric: a rider who actually walked may report the car to appear environmentally motivated, but a rider who actually drove has little reason to report walking, so self-reports plausibly inflate the walking share and deflate the car share rather than the reverse. This asymmetry, combined with the young smartphone-using samples that dominate operator surveys, explains why the survey arm and the revealed arm disagree in a consistent direction.

Car substitution, where it occurs, is concentrated and conditional. Gebhardt et al.(2)and Gebhardt, Ehrenberger, Wolf and Cyganski,(26)who estimated that 13 percent of daily German car trips and 2 percent of car kilometres were suitable for replacement, both found that the saving potential depends on trip length, purpose and weather rather than on the scooter alone.

Lee et al.(18)located the largest substitution in carpool and taxi trips, and Guo and Zhang(27) reported that auto mode substitution grew with specific trip contexts. The conditionality matters for policy because a blanket deployment captures far more walking and transit trips than car trips,

as the Swedish cities studied by Gao et al.(15)demonstrated.

Life-cycle emission factors vary by an order of magnitude, and the drivers are operational rather than technological. The 202 g CO2e per passenger-mile of Hollingsworth, Copeland and Johnson(1)fell to 141 g when scooter lifetime was extended, to 164 g when collection was limited to low-battery scooters and to 147 g when collection driving distance was reduced, and the 165 g CO2e per kilometre of Kazmaier, Taefi and Hettesheimer(21)fell to 46 g under battery swapping and longer lifetimes.

Judl et al.(22)and Jia and Gao(23)showed that lifetime mileage and the electricity mix dominate the result, which is why Moreau et al.(6)and Baumgartner and Helmers(28)concluded that short-lived fleets in fossil-heavy grids can erase any substitution benefit.

The reviews of Calan, Sobrino and Vassallo(9)and Arbeláez Vélez(8)reached the same conclusion across a larger corpus, and Balıkçı and Dündar(29)reported the same dependence for Istanbul.

Baumgartner and Helmers,(28)consolidating published assessments, estimated that the reported values carry an average bias of 34 percent because end-of-life impacts were not modelled, which cautions against treating any single published factor as definitive.

System boundary choices explained part of the emission spread. The integrated modal assessment of de Bortoli(25)included pavement and infrastructure, whereas the product-level assessments of Hollingsworth, Copeland and Johnson(1)and Moreau et al.(6)excluded them, so the lower values of the integrated assessment are not directly comparable with the higher product-level values. Future assessments should report the boundary explicitly to allow like-for-like comparison.

One further distinction explains residual disagreement. Studies that asked about the entire journey found that e-scooters replace the whole trip, whereas studies that separated access and egress found that many scooter trips serve a feeder role whose alternative would have been another short mode. The access-egress share of Fearnley(13)replaced walking in 77.9 percent of cases, which means the mode substituted an active feeder rather than a motorized journey when it served transit, a nuance that a single substitution share cannot convey.

A positive climate outcome therefore turns on a double condition that few cities satisfy at once: the scooter must replace a motorized trip and the fleet must operate with a long lifetime in a low-carbon grid. de Bortoli and Christoforou(24)measured a net increase of 13,000 tonnes of CO2eq in Paris, where short lifetimes and fossil electricity prevailed, whereas de Bortoli(25)placed the same mode below the car but above public transport and walking, and Felipe-Falgas, Madrid-Lopez and Marquet(30)reported that self-reported modal change in Barcelona only partially offset operational emissions.

Sun and Ertz(31)and Sun, Zhang and Ertz(32)reported similar conditionality at city scale, and Mandouri et al.(33)identified the utilization rate as the single most important lever. Unlike the early optimistic operator claims, the empirical record indicates that positive net effects are the exception rather than the rule.

Prior reviews anticipated these findings but could not state them jointly. Wang et al.(7)documented the walking-dominated survey pattern, and Badia and Jenelius(3)noted the wide dispersion of both substitution and emission estimates without resolving their relation. The meta-analysis of Fearnley and Veisten(10)pooled the substitution proportions, and Marques and Coelho(34)argued that life-cycle thinking must be integrated into micromobility research; the present synthesis shows that the two literatures are two halves of a single answer, because the emission factor only becomes a climate outcome once it is multiplied by the substituted mode. Şengül and Mostofi(11) reached the same caution from the sustainability side.

The pooled estimates of the available meta-analysis are consistent with the survey arm of this synthesis but cannot represent the revealed arm. Fearnley and Veisten(10)aggregated substitution proportions across survey studies and recovered the walking-dominated pattern, yet the natural experiment of Asensio et al.(17)and the inference of Wan and Bendavid(16)cannot enter such a pool because they report travel-time changes or inferred probabilities rather than stated shares. A pooled survey estimate therefore describes what riders say, not what the mode does, and the two quantities diverge systematically.

Shared and private ownership also mattered for substitution. Aarhaug, Egner and Fearnley(35) compared usage and mode replacement between shared and personal e-scooters and found the substitution profile depended on ownership, and Christoforou et al.(36)reported that more than 16 percent of participants' private car use in Paris was replaced by e-scooters.

Reck, Martin and Axhausen(4)modelled mode choice with both shared and personal e-scooters and found the two attracted different trip types. This distinction matters because the review focused on shared vehicles, and the emissions of a shared vehicle include collection and relocation that a private vehicle avoids, which is one reason the shared emission factor of Moreau et al.(6)

exceeded the private one, 131 against 67 g CO2eq per passenger-kilometre in Brussels.

The relation with public transport was ambiguous rather than simply substitutive. Vinagre Díaz et al.(19)found that half of Rome trips substituted transit while the other half served transit-poor areas, and Jayawardhena et al.(37)reviewed the conditions under which e-scooters complement or compete with public transport.

Wang et al.(38)measured a 30 to 35 percent substitution rate for shared mobility hubs in Manchester with a modest increase in public transport use, and Bösehans, Bell and Dissanayake(39) reported similar findings across European users. Weschke, Oostendorp and Hardinghaus(40)linked mode shift to motivational reasons in German shared e-scooter usage, which reinforces the conclusion that the same trip can be either a feeder or a competitor depending on network design.

The geographic base of the evidence was narrow, and its findings may not transfer. Most included studies came from Northern and Western European cities and a few United States cities, while Echeverría-Su et al.(41)reported for Lima that the local vehicle stock and electricity mix changed the environmental balance, and Yan et al.(42)found that the potential of e-scooters to serve transit depended on network structure.

Cities with dense transit and short trips concentrate the walking and public transport substitution that erodes benefits, whereas car-dependent cities with poor transit offer the motorized substitution that creates them, so the same regulation could be right in one context and wrong in another.

The review retrieved only open access full texts, and 29 eligible reports could not be obtained, which may over-represent studies with deposit mandates and under-represent industry surveys published behind paywalls such as the French trial surveys of Krier et al..(43)Grey literature and operator trial reports were not searched systematically, so substitution estimates published outside the indexed literature are missing by construction.

The restriction to English may exclude studies from Asian and Latin American cities that Echeverría-Su et al.(41)and Yan et al.(42)suggest would show different substitution patterns, and the hypothetical nature of survey substitution shares cannot be fully validated against observed behaviour.

Future research should replace the counterfactual with observation. Pairing in-app stated-alternative questions with trip records, as Reck, Martin and Axhausen(4)and Christoforou et al.(36) began to do, would reveal whether stated shares match revealed shares, and longitudinal designs could measure whether substitution persists after novelty fades.

Life-cycle assessments would gain comparability from standardized lifetime, electricity and boundary assumptions, since the current 30 to 320 g CO2e per passenger-kilometre span reflects assumption differences at least as much as real differences between cities.

The certainty of the evidence is highest for the survey pattern and lowest for the net effect. The claim that walking and public transport dominate substitution rests on several independent surveys and is unlikely to be overturned, whereas the claim that a given city will achieve net reductions depends on lifetime and electricity parameters that the included life-cycle assessments treated as scenarios rather than as observations.

Decision makers should therefore treat the substitution finding as established and the net-effect finding as conditional, and should require operator telemetry on lifetime and collection mileage before crediting a fleet with avoided emissions.

The moderate risk ratings in the survey arm do not erase the direction of the finding, but they caution against adopting any single percentage as a planning constant. A municipality that treats the 46.9 percent walking share of Norway or the 8.9 percent car share of Bristol as its own forecast would inherit the sampling and wording choices of those studies. The robust message is the ordering, walking and public transport first and the car a minority, not any single number, and that ordering held across every survey regardless of risk rating.

Three operational levers follow directly from the emission factors. Battery swapping reduced the German estimate by 12 percent, limiting collection to low-battery scooters reduced the United States estimate by about 19 percent, and extending lifetime reduced it by roughly 12 to 30 percent depending on the baseline, which together can move a fleet from the polluting to the beneficial side of the ledger without any change in substitution. Regulation that requires operators to report lifetime mileage, collection distance and charging emissions would convert these scenario assumptions into verifiable performance metrics.

The substitution pattern also carries an equity reading. Where e-scooters replace walking, the health and accessibility benefits of active travel are traded for a paid ride, and where they replace public transport, the revenue of a subsidized collective mode is eroded for the benefit of a private operator. The included evidence cannot quantify these distributional effects, but it locates them:

they are largest in the dense, transit-rich and walkable settings where the walking-dominated substitution is strongest, which is the opposite of the car-dependent settings where the climate benefit would be largest.

For practice, the evidence supports policies that target the conditional cases rather than the mode as such. Fleet caps, minimum lifetime requirements and relocation toward low-battery collection raise the environmental performance of every scooter regardless of substitution, and integration with transit fares, as examined by Jayawardhena et al.,(37)may convert first-and-last-mile complementarity into car replacement instead of transit cannibalization.

Induced travel deserves attention as well, since Fearnley and Veisten(44)showed that a share of e-scooter trips would not otherwise exist, and Zhang, Nelson, Mulley and Kent(45)found that trial evaluations rarely measure that counterfactual. The balance of the included evidence is that shared e-scooters are not inherently green or inherently polluting; their climate value is earned at the fleet level and at the trip level, one substitution at a time.

The remaining uncertainty is empirical rather than conceptual. The review establishes that substitution is the hinge and that lifetime and electricity are the levers; what is missing is longitudinal evidence on whether substitution persists after novelty fades and whether fleets achieve the lifetimes their operators claim. Closing that gap requires the telemetry that operators already collect, and the present synthesis suggests that releasing such data would settle more of the climate debate than any further rider survey could ever do, because the decisive parameters are already recorded in every rental transaction and every charging cycle.

CONCLUSIONS

Shared e-scooter trips most often replace walking and public transport rather than the private car, with car replacement shares of roughly 3 to 13 percent in self-reported surveys and up to about 34 percent in inferred and revealed-preference studies, while life-cycle greenhouse gas emissions range from 30 to 320 g CO2e per passenger-kilometre depending on scooter lifetime, electricity mix and fleet operations. Net emission reductions occur only where the scooter replaces a motorized trip and the fleet achieves a long lifetime in a low-carbon grid; in most observed settings the mode displaces active and public transport trips and can increase emissions.

The policy implication is direct: cities that seek a climate benefit should regulate the operational conditions and steer the mode toward the car trips it can genuinely replace, rather than assume that every shared scooter is inherently low-carbon, and should verify those conditions with operator data before crediting emission savings.

REFERENCES

1. Hollingsworth J, Copeland B, Johnson JX. Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. Environ Res Lett. 2019;14(8):084031. doi: 10.1088/1748-9326/ab2da8
2. Gebhardt L, Wolf C, Seiffert R. "I'll Take the E-Scooter Instead of My Car"—The Potential of E-Scooters as a Substitute for Car Trips in Germany. Sustainability. 2021;13(13):7361. doi: 10.3390/su13137361
3. Badia H, Jenelius E. Shared e-scooter micromobility: review of use patterns, perceptions and environmental impacts. Transport Reviews. 2023;43(5):811-837. doi: 10.1080/01441647.2023.2171500
4. Reck DJ, Martin H, Axhausen KW. Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility. Transportation Research Part D: Transport and Environment. 2022;102:103134. doi: 10.1016/j.trd.2021.103134
5. Laa B, Leth U. Survey of E-scooter users in Vienna: Who they are and how they ride. Journal of Transport Geography. 2020;89:102874. doi: 10.1016/j.jtrangeo.2020.102874
6. Moreau H, de Jamblinne de Meux L, Zeller V, D'Ans P, Ruwet C, Achten WMJ. Dockless E-Scooter: A Green Solution for Mobility? Comparative Case Study between Dockless E-Scooters, Displaced Transport, and Personal E-Scooters. Sustainability. 2020;12(5):1803. doi: 10.3390/su12051803
7. Wang K, Qian X, Fitch DT, Lee Y, Malik J, Circella G. What travel modes do shared e-scooters displace? A review of recent research findings. Transport Reviews. 2023;43(1):5-31. doi: 10.1080/01441647.2021.2015639
8. Arbeláez Vélez AM. Environmental impacts of shared mobility: a systematic literature review of life-cycle assessments focusing on car sharing, carpooling, bikesharing, scooters and moped sharing. Transport Reviews. 2024;44(3):634-658. doi: 10.1080/01441647.2023.2259104
9. Calan C, Sobrino N, Vassallo JM. Understanding Life-Cycle Greenhouse-Gas Emissions of Shared Electric Micro-Mobility: A Systematic Review. Sustainability. 2024;16(13):5277. doi: 10.3390/su16135277
10. Fearnley N, Veisten K. What proportions of different transport modes do e-scooters replace? A meta-analysis. Journal of Cycling and Micromobility Research. 2025;5:100082. doi: 10.1016/j.jcmr.2025.100082
11. Şengül B, Mostofi H. Impacts of E-Micromobility on the Sustainability of Urban Transportation—A Systematic Review. Applied Sciences. 2021;11(13):5851. doi: 10.3390/app11135851
12. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021:n71. doi: 10.1136/bmj.n71
13. Fearnley N. Factors Affecting e-Scooter Mode Substitution. Findings. 2022;2022. doi: 10.32866/001c.36514
14. Speak A, Taratula-Lyons M, Clayton W, Shergold I. Scooter Stories: User and Non-User Experiences of a Shared E-Scooter Trial. Active Travel Studies. 2023;3(1). doi: 10.16997/ats.1195
15. Gao K, Jia R, Liao Y, Liu Y, Najafi A, Attard M. Big-data-driven approach and scalable analysis on environmental sustainability of shared micromobility from trip to city level analysis. Sustainable Cities and Society. 2024;115:105803. doi: 10.1016/j.scs.2024.105803
16. Wan L, Bendavid I. Inferring trip purposes and mode substitution effect of rental e-scooters in London. Transportation Research Part D: Transport and Environment. 2024;126:104034. doi: 10.1016/j.trd.2023.104034
17. Asensio OI, Apablaza CZ, Lawson MC, Chen EW, Horner SJ. Impacts of micromobility on car displacement with evidence from a natural experiment and geofencing policy. Nat Energy. 2022;7(11):1100-1108. doi: 10.1038/s41560-022-01135-1
18. Lee M, Chow JYJ, Yoon G, He BY. Forecasting e-scooter substitution of direct and access trips by mode and distance. Transportation Research Part D: Transport and Environment. 2021;96:102892. doi: 10.1016/j.trd.2021.102892
19. Vinagre Díaz JJ, Fernández Pozo R, Rodríguez González AB, Wilby MR, Anvari B. Blind classification of e-scooter trips according to their relationship with public transport. Transportation. 2024;51(5):1679-1700. doi: 10.1007/s11116-023-10382-4
20. Kazemzadeh K, Sprei F. The effect of shared e-scooter programs on modal shift: Evidence from Sweden. Sustainable Cities and Society. 2024;101:105097. doi: 10.1016/j.scs.2023.105097
21. Kazmaier M, Taefi TT, Hettesheimer T. Techno-Economical and Ecological Potential of Electric Scooters: A Life Cycle Analysis. EJTIR. 2020;20(4):233-251. doi: 10.18757/ejtir.2020.20.4.4912
22. Judl J, Horn S, Mosoni C, Suomalainen E. Life cycle and critical raw material analysis of shared e-scooters in Helsinki, Finland. Int J Life Cycle Assess. 2026;31(7):121. doi: 10.1007/s11367-026-02685-2
23. Jia R, Gao K. Life-cycle analysis of shared e-scooter: data-driven approaches in 100 EU cities. Transportation Research Part D: Transport and Environment. 2025;148:105009. doi: 10.1016/j.trd.2025.105009
24. de Bortoli A, Christoforou Z. Consequential LCA for territorial and multimodal transportation policies: method and application to the free-floating e-scooter disruption in Paris. Journal of Cleaner Production. 2020;273:122898. doi: 10.1016/j.jclepro.2020.122898
25. de Bortoli A. Environmental performance of shared micromobility and personal alternatives using integrated modal LCA. Transportation Research Part D: Transport and Environment. 2021;93:102743. doi: 10.1016/j.trd.2021.102743
26. Gebhardt L, Ehrenberger S, Wolf C, Cyganski R. Can shared E-scooters reduce CO2 emissions by substituting car trips in Germany?. Transportation Research Part D: Transport and Environment. 2022;109:103328. doi: 10.1016/j.trd.2022.103328
27. Guo Y, Zhang Y. Understanding factors influencing shared e-scooter usage and its impact on auto mode substitution. Transportation Research Part D: Transport and Environment. 2021;99:102991. doi: 10.1016/j.trd.2021.102991

28. Baumgartner C, Helmers E. Life cycle assessment of electric kick scooters: consolidating environmental impact quantification and concluding climate-friendly use options. Environ Sci Eur. 2024;36(1):96. doi: 10.1186/s12302-024-00920-x
29. Balıkçı AK, Dündar S. Cradle-to-Grave Carbon Emissions of Shared E-Scooters in Istanbul: An LCA-Based Analysis. 2026 6th International Conference on Electrical, Computer and Energy Technologies (ICECET). 2026:1-6. doi: 10.1109/icecet65726.2026.11633231
30. Felipe-Falgas P, Madrid-Lopez C, Marquet O. Assessing Environmental Performance of Micromobility Using LCA and Self-Reported Modal Change: The Case of Shared E-Bikes, E-Scooters, and E-Mopeds in Barcelona. Sustainability. 2022;14(7):4139. doi: 10.3390/su14074139
31. Sun S, Ertz M. Can shared micromobility programs reduce greenhouse gas emissions: Evidence from urban transportation big data. Sustainable Cities and Society. 2022;85:104045. doi: 10.1016/j.scs.2022.104045
32. Sun S, Zhang J, Ertz M. The Energy and Environmental Impacts of Free-Floating Shared E-Scooters: A Multi-City Life Cycle Assessment. Energies. 2025;18(23):6259. doi: 10.3390/en18236259
33. Mandouri J, Onat NC, Mohammad A, Kucukvar M, Sen B, Al Nawaiseh HM, et al. Hybrid life cycle sustainability assessment of shared e-scooters: utilization rate as a key driver of sustainability performance. Int J Life Cycle Assess. 2025;30(9):2053-2067. doi: 10.1007/s11367-025-02510-2
34. Marques DL, Coelho MC. A Literature Review of Emerging Research Needs for Micromobility—Integration through a Life Cycle Thinking Approach. Future Transportation. 2022;2(1):135-164. doi: 10.3390/futuretransp2010008
35. Aarhaug J, Egner LE, Fearnley N. Does e-scooter ownership matter? A comparison of usage patterns and mode replacement effects of shared vs. personal e-scooters. Research in Transportation Economics. 2025;113:101626. doi: 10.1016/j.retrec.2025.101626
36. Christoforou Z, de Bortoli A, Gioldasis C, Seidowsky R. Who is using e-scooters and how? Evidence from Paris. Transportation Research Part D: Transport and Environment. 2021;92:102708. doi: 10.1016/j.trd.2021.102708
37. Jayawardhena M, Delbosc A, Currie G, Rose G. When do shared e-scooters complement or compete with public transport? A mixed-method review and comparison with bike sharing. Journal of Cycling and Micromobility Research. 2025;3:100057. doi: 10.1016/j.jcmr.2025.100057
38. Wang H, Bell MC, Dong J, Burke M, Ayan H, Dissanayake D. Quantifying carbon reductions from mode substitution through shared electric mobility hubs in Greater Manchester. Sci Rep. 2025;15(1):38815. doi: 10.1038/s41598-025-22719-3
39. Bösehans G, Bell MC, Dissanayake D. Shared mobility - Novel insights on mode substitution patterns, trip and user characteristics. Journal of Cycling and Micromobility Research. 2024;2:100029. doi: 10.1016/j.jcmr.2024.100029
40. Weschke J, Oostendorp R, Hardinghaus M. Mode shift, motivational reasons, and impact on emissions of shared e-scooter usage. Transportation Research Part D: Transport and Environment. 2022;112:103468. doi: 10.1016/j.trd.2022.103468
41. Echeverría-Su M, Huamanraime-Maquin E, Cabrera FI, Vázquez-Rowe I. Transitioning to sustainable mobility in Lima, Peru. Are e-scooter sharing initiatives part of the problem or the solution?. Science of The Total Environment. 2023;866:161130. doi: 10.1016/j.scitotenv.2022.161130
42. Yan X, Zhao X, Broaddus A, Johnson J, Srinivasan S. Evaluating shared e-scooters' potential to enhance public transit and reduce driving. Transportation Research Part D: Transport and Environment. 2023;117:103640. doi: 10.1016/j.trd.2023.103640
43. Krier C, Chrétien J, Lagadic M, Louvet N. How Do Shared Dockless E-Scooter Services Affect Mobility Practices in Paris? A Survey-Based Estimation of Modal Shift. Transportation Research Record: Journal of the Transportation Research Board. 2021;2675(11):291-304. doi: 10.1177/03611981211017133
44. Fearnley N, Veisten K. A Meta-analysis of the Induced Travel due to E-scooters. Findings. 2026. doi: 10.32866/001c.166736
45. Zhang Y, Nelson JD, Mulley C, Kent JL. Reflections on the value of trials: Insights from the shared e-scooter trial evaluation in New South Wales, Australia. Transport Policy. 2026;187:104303. doi: 10.1016/j.tranpol.2026.104303

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